

# PERFORMANCE OF RATS UNDER CONCURRENT VARIABLE-INTERVAL SCHEDULES OF NEGATIVE REINFORCEMENT

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The behavior of rats under concurrent variable-interval schedules of negative reinforcement was examined. A single one-minute variable-interval programmer determined the availability of 30-second timeouts from electric shock. These were assigned to one or the other of the two component schedules with a probability of 0 to 1.0. The response requirement for the component schedules was standing to the right or left of the center of the experimental chamber. With a six-second changeover delay, the relative time spent under one component schedule varied directly and linearly with the relative number of timeouts earned under that component schedule. The absolute number of changeovers was highest when a similar number of timeouts was earned under each component schedule, and lowest when all or nearly all timeouts were earned under one component schedule. In general, these relations are similar to those reported with concurrent variable-interval schedules of positive reinforcement.

*Key words:* concurrent variable-interval schedule, timeout, negative reinforcement, electric shock, time matching, changeover delay, rats

Behavior under concurrent variable-interval (VI) schedules of positive reinforcement has been studied extensively. In general, the relative number of responses (or the relative time spent) under one component schedule is directly and linearly related to the relative number (or magnitude, or intensity—see deVilliers, 1977) of reinforcers received under that schedule. This relation has been labelled the “matching law”, which was initially formulated (Herrnstein, 1961) as:

$$\frac{R_1}{R_1 + R_2} = \frac{r_1}{r_1 + r_2}, \quad (1)$$

where  $R_1$  and  $R_2$  are number of responses per session under each component and  $r_1$  and  $r_2$  are number of reinforcers delivered under each component. When time spent under each component schedule is the dependent variable, the equation becomes:

$$\frac{T_1}{T_1 + T_2} = \frac{r_1}{r_1 + r_2}, \quad (2)$$

where  $T_1$  and  $T_2$  are time spent under each component and  $r_1$  and  $r_2$  are number of reinforcers delivered under each component.

These equations (1 and 2) specify what deVilliers (1977, p. 238) termed “relative proportion matching”, and account well for much data obtained when concurrent VI schedules are arranged (*e.g.*, Brownstein and Pliskoff, 1968; Catania, 1963; Herrnstein, 1961; McSweeney, 1975). However, in some cases, obtained data do not fit these equations well. For example, Baum and Rachlin (1969) studied the behavior of pigeons, when standing on one or the other side of an experimental chamber was reinforced on two concurrent VI schedules. Their data were best accounted for by a “proportional ratio matching equation”, (deVilliers, 1977, p. 238), of the form:

$$\frac{T_1}{T_2} = k \frac{r_1}{r_2}, \quad (3)$$

where  $T_1$  and  $T_2$  are the times spent under each component and  $r_1$  and  $r_2$  are reinforcers delivered under each component. Equation 3 is generally, but not necessarily, expressed in logarithmic coordinates. In this log form,  $k$  is the intercept of the Y-axis when  $\log(r_1/r_2) = 0$  and serves as a bias factor accounting for unknown reinforcers in the experimental setting.

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These reinforcers result in systematic departures from a simple matching relation (Equations 1 and 2). DeVilliers (1977) noted that the proportional ratio matching equation (3) is more general than the relative proportion matching equation (1 and 2): when relative proportion matching is obtained, proportional ratio matching must also hold, although the converse is not always true. However, much data collected under concurrent VI schedules of positive reinforcement is equally well described by the proportional ratio matching and relative proportion matching equations (deVilliers, 1977).

Behavior under concurrent schedules of negative reinforcement is understood less thoroughly than behavior under concurrent schedules of positive reinforcement. Baum (1973) studied pigeons under a schedule in which standing on one or the other side of a chamber was reinforced with timeout from electric shock under concurrent VI schedules, and found his data to be well described by Equation 3 above. Perhaps due to Baum's technical difficulties with shocking pigeons, further studies of this sort have not appeared. The present research examined the behavior of rats under concurrent VI schedules, where the reinforced response was occupation of a specified area, and the availability of timeouts from electric shock under each component schedule was arranged according to a procedure devised by Stubbs and Pliskoff (1969). Under this procedure, one VI programmer arranges reinforcer availability for both component schedules. When a reinforcer becomes available, it is probabilistically assigned to one or the other component, and another reinforcer does not become available until the initial reinforcer is delivered. Stubbs and Pliskoff (1969) reported good matching of relative response rate (and relative time) and relative reinforcement frequency when food reinforcement was arranged according to this procedure, but it has not been utilized to study negative reinforcement.

## METHOD

### *Subjects*

Three adult male Sprague-Dawley rats were individually housed with unlimited access to water in a constantly-illuminated room with an ambient temperature of 24°C. Each animal

was maintained at a 400-g body weight, which was within  $\pm 5\%$  of the free-feeding weight.

### *Apparatus*

A 25- (height) by 25- (depth) by 60-cm experimental chamber, similar to that described by Baum and Rachlin (1969) was fabricated of plywood. A 7-W white bulb located in the ceiling of the chamber provided ambient illumination and an exhaust fan supplied ventilation and masking noise. A speaker centered in the front wall delivered white noise during changeover delays. The floor of the chamber consisted of two adjacent platforms constructed of 0.2-cm diameter metal grids spaced 1.0 cm apart. When a downward pressure of greater than 200 N was applied to the right platform, it dropped 0.4 cm, operating a microswitch. Time spent by a subject on the right side was measured by determining the total time during which the microswitch was operated (closed); time spent on the left side was measured by subtracting this figure from total session time. Absolute number of microswitch operations provided a measure of changeovers: movement from the left to the right side of the chamber caused the opened switch to be closed, which was recorded as a changeover; movement from the right to the left side opened the closed switch, which was also recorded as a changeover. Electromechanical control and recording equipment were located outside the chamber.

### *Procedure*

Throughout the study, scrambled 0.75-sec, 5-mA electric shocks (measured at the grid) were delivered at 2-sec intervals so long as the chamber was illuminated. Reinforcers consisted of 30-sec timeouts, during which all lights were extinguished and no shocks were delivered. During the first 20 sessions of initial training, a timeout occurred each time the subject moved from one platform to the other. This procedure was instituted in an attempt to reduce the immobility associated with shock delivery. During Sessions 21 to 40 of initial training, timeouts were available under a concurrent VI 30-sec VI 30-sec schedule; a concurrent VI 1-min VI 1-min schedule was in effect during Sessions 41 to 55. During all sessions, the response requirement for one component schedule (VI<sub>1</sub>) was occupation of the left platform; occupation of the right platform was the

response requirement for the second component schedule ( $VI_2$ ). A 6-sec changeover delay (COD) was constantly in effect, so that the subject had to remain on one platform for at least 6 sec before a timeout was initiated. If the subject moved from one side of the chamber before the COD expired, that COD terminated and a second 6-sec COD was arranged. This assured that no timeouts occurred less than 6 sec after a changeover, although an individual COD could be less than 6 sec. White noise was supplied to the chamber during all CODs.

Following initial training, each animal was exposed to a procedure under which timeout availability was determined by a single  $VI$  programmer, with a value of  $VI$  1-min (and a distribution of intervals like that recommended by Fleshler and Hoffman, 1962) being used during all sessions. Timeouts were randomly assigned to one of the two component schedules with a probability of 0, 0.1, 0.23, 0.5, 0.73, or 1.0. Response requirements and the COD value remained the same as in initial training.

Each probability with which a timeout was assigned to a component schedule constituted an experimental condition, and each animal was exposed to each condition twice. The order of exposure for each subject is shown in Table 1. During each exposure, animals were trained until the mean time spent under component  $VI_1$  during sessions  $N$  and  $N + 1$  was within  $\pm 10\%$  of the mean time spent under

that component during Sessions  $N + 1$  and  $N + 2$ . Each subject was exposed to three sessions per day, with the sessions separated by 3 to 4 hr. All sessions terminated after a total of 30 timeouts were earned on the two component schedules. Thus, zero timeouts were delivered per session on  $VI_1$  when the probability for that component was zero, 15 were delivered when the probability was 0.5, and 30 were delivered when the probability was 1.0.

For R7, a mean of 39 sessions was required to meet the above stability criterion, with a range across conditions of 17 to 71 sessions. Subject R8 reached stability, on the average, in 51 sessions (with a range across conditions of 30 to 69), while R9 reached stability after a mean of 32 sessions (range across conditions eight to 53).

During each session, time spent under component schedule  $VI_1$ , time spent under component schedule  $VI_2$ , and total changeovers were recorded. The methods used to collect these data are described above.

## RESULTS

Table 1 shows the total amount of time spent under each component schedule during the final three sessions of each experimental condition. For all subjects, relative amount of time spent under a component schedule typically increased directly with the relative number of timeouts delivered under that compo-

Table 1

Total amount of time (in minutes) spent under each component schedule during the final three sessions of each experimental condition. Conditions are labelled according to the proportion of timeouts assigned to component schedule  $VI_1$ . The numbers in parentheses refer to the order in which conditions appeared.

Proportion of Timeouts, $VI_1$	R7		R8		R9	
	$VI_1$	$VI_2$	$VI_1$	$VI_2$	$VI_1$	$VI_2$
0	(1) 5.7	153.9	(4) 7.9	141.6	(9) 5.6	151.7
	(7) 7.6	141.8	(9) 6.3	150.6	(6) 2.3	161.8
0.1	(5) 21.2	138.2	(10) 20.8	140.0	(1) 28.3	127.7
	(12) 15.2	130.3	(11) 44.4	120.0	(5) 28.6	130.3
0.24	(9) 53.7	105.6	(12) 57.3	95.1	(11) 39.7	121.3
	(11) 49.5	111.1	(3) 52.6	113.3	(4) 39.9	126.6
0.5	(10) 90.3	78.6	(1) 106.2	60.6	(10) 99.3	72.3
	(8) 89.4	75.3	(6) 74.7	79.7	(8) 78.3	83.4
0.73	(3) 117.6	54.0	(2) 138.3	32.7	(7) 113.4	40.2
	(4) 127.5	28.6	(8) 147.4	29.1	(12) 102.2	69.3
1.0	(2) 159.6	12.3	(5) 150.3	8.9	(3) 158.3	9.4
	(6) 158.3	6.6	(7) 156.3	14.4	(2) 145.1	13.3

nent. Note that the total time spent under the two component schedules is invariably greater than 90 min, the minimum time required to complete three sessions. This reflects time spent in CODs, and time spent under a component schedule in which a timeout was not available. Average COD values less than 6 sec reflect CODs that occurred less than 6 sec apart.

Figure 1 plots data in terms of the relative proportion matching equation (2): time spent under  $VI_1$ /time spent under  $VI_1$  + time spent under  $VI_r$  graphed as a function of timeouts earned under  $VI_1$ /timeouts earned under  $VI_1$  + timeouts earned under  $VI_r$ . For each subject, a line fitted to the data points provides a best fit (accounting for over 88% of the variance in all cases) with a slope of slightly less than one, and a Y-intercept of near zero. This indicates weak undermatching, a slight tendency to spend more time under the less-frequently reinforced component schedule than would be predicted by the matching equation.

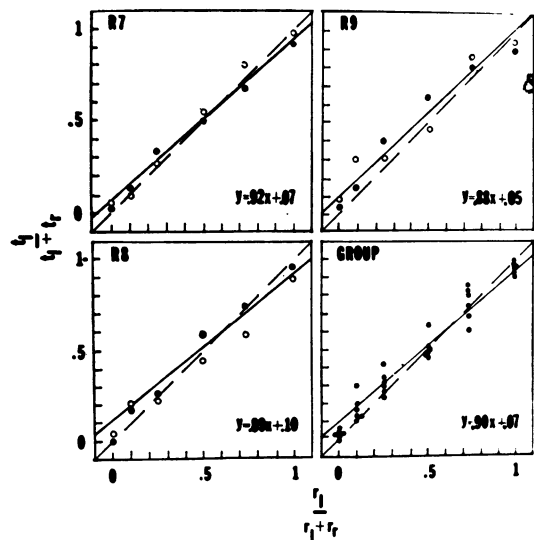


Fig. 1. Relative time spent under component schedule  $VI_1$  as a function of relative number of timeouts earned under that component schedule. Equations along the axes are explained in text. The dotted line represents perfect matching; the solid line was fitted to the data by the method of least squares. The equation within each frame describes the line of best fit for the data therein. Each data point represents three consecutive sessions. For individual animals, closed circles represent the first exposure to each condition; open circles represent the second exposure.

Figure 2 shows total number of changeovers during the final three sessions of each experimental condition. Number of changeovers was generally lowest when most timeouts were delivered under one or the other component schedule (*i.e.*, at probabilities of 0, 0.1, and 1.0), and increased as the number of timeouts delivered under each component schedule became more equal (*i.e.*, as the probability approached 0.5). This pattern held for all animals, although the absolute number of changeovers varied considerably across subjects.

## DISCUSSION

The present results indicate that the relative time spent under each component of a concurrent VI schedule of negative reinforcement varies directly and linearly with the relative number of reinforcers earned under that component schedule. This relation is similar to that previously reported when behavior under concurrent VI schedules of positive reinforcement was examined (*e.g.*, Catania, 1963; Herrnstein, 1961; Reynolds, 1963). Data from the present study were relatively well described by the relative proportion matching equation (2). They would also be described by the proportional ratio matching equation (3). DeVilliers (1977) noted that this equation (with its response-based counterpart) accurately described the data collected in a large number of studies of performance under concurrent

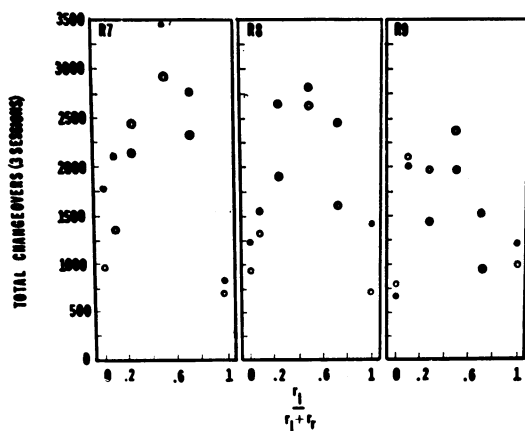


Fig. 2. Total changeovers during the last three sessions at each experimental condition. Closed circles represent the first exposure, open circles represent the second exposure. Conditions are labelled according to the relative number of timeouts earned under component schedule  $VI_1$ .

schedules of positive reinforcement, and also describes data reported by Baum (1973), who studied pigeons performing under concurrent schedules of negative reinforcement. However, Baum's data, unlike those of the present study, were not well described by the relative proportion matching equation (2). A variety of factors, beyond the species studied, may account for this difference.

One such factor is the manner in which timeout availability was scheduled: in the present study, timeout availability for both component schedules was determined by a single VI programmer, then allocated to one of the component schedules with a probability of 0 to 1.0, while the component VI schedules were independently arranged in Baum's study.

Response measures also differed in the two studies. Time allocation in the present study was dichotomized into two discreet categories: time spent under component VI<sub>1</sub>, and time spent under component VI<sub>2</sub>. Baum (1973) included a third category, essentially time spent under both components (*i.e.*, in the middle of the chamber). Baum's subjects spent a relatively large amount of time in the middle of the chamber, and nonsystematic observations indicated that subjects also spent a good deal of time in the middle of the chamber in the present study. However, since this datum was not systematically recorded in the present study, direct comparison between the two studies is rendered difficult. Nonetheless, both studies do indicate that relative time spent under each component of a concurrent VI schedule of negative reinforcement varies lawfully with the relative number of reinforcers received under that component, supporting Baum's contention that aversive control may be adequately handled within the conceptual framework of the matching relation.

In the present study, as in Baum's study (1973) and earlier studies of positive reinforcement (*e.g.*, Brownstein and Pliskoff, 1968; Herrnstein, 1961), the number of changeovers was highest when a similar number of reinforcers were earned under each component schedule, and lowest when most reinforcers were earned under one component. Research with positive reinforcement has generally indicated that the number of changeovers varies inversely with changeover delay (COD) length. Effects of COD length on changeover rate under concurrent schedules of negative reinforcement

have not been evaluated; the study by Baum (1973) and the present study used a single COD value and found relatively high changeover rates. However, the COD value in both studies was apparently sufficient to "separate" the component schedules in time, since relatively good matching occurred. Baum (1973) did note that the consistent undermatching shown by one subject may have resulted from the brief (1-sec) COD studied, and the weak undermatching shown by all subjects in the present study may also have been related to COD duration: while the 6-sec COD value used was appreciably longer than those values typically used in studies of concurrent schedules of positive reinforcement (see deVilliers, 1977, Tables 1 and 2), most of these studies used pigeons as subjects. Longer values are often required for matching to obtain with rats under schedules of positive reinforcement (deVilliers, 1977), and a similar relation might well be expected to hold with negative reinforcement, although direct confirmation is lacking at present.

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